# PLANETARY SCALING LAWS AND PREDICTIONS FOR NEPTUNE

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## Abstract

In this paper I offer a prediction concerning Neptune's low–frequency radio emission based on the radiometric Bode's law in combination with a recent prediction for Neptune's global magnetic field strength. The latter is based on a dynamo scaling relation derived from the magnetospheric balance condition within planetary cores. The radio emission frequency range is predicted to extend from approximately 100 to 1000 kHz, with a spectral peak between 350 and 500 kHz. A crude estimate of the emission spectral shape, based on Saturn and earth–like models, is shown. If radiation is beamed approximately in the sunward direction, Neptune should be detectable by the Planetary Radio Astronomy experiment onboard the Voyager spacecraft sometime between 45 and 60 days before closest approach.

## 1. Introduction

The earth, Jupiter, Saturn and Uranus are now known to be sources of intense non–thermal radio bursts. This situation allows low–frequency radio astronomers the unprecedented opportunity to compare the morphologies of these diverse radio emissions, comparisons which may reveal general laws relating power inputs and outputs. Although not all of the radio planets possess a readily identifiable correlation with the solar particle input, there appears to be a heuristic relationship (dubbed the "radiometric Bode's Law" by Desch and Kaiser, 1984) between the solar wind input to the magnetospheres of each planet and that fractional part of the radio emission output which is not satellite driven (e.g. Io controlled). With the impending encounter of Voyager 2 with Neptune in 1989, interest in that planet increases. A recent prediction by Curtis and Ness (1986) of Neptune's internal field strength permits an estimate of the radio emission output likely to be observed at Neptune if the radiometric Bode's law continues to hold.

## 2. Results

The calculation of the mean planetary efficiency, described in the following two paragraphs, follows the discussion by Desch and Kaiser (1984). Briefly, the total radiated powers of the terrestrial (Kaiser and Alexander, 1977), Jovian (Carr et al., 1983), Saturnian (Kaiser et al., 1981), and Uranian (Warwick et al., 1986) radio sources have been estimated in previous studies. We have been careful in estimating total radiated powers to use the measured or inferred beam geometry of each source and to include only that portion of each planet's spectrum that is known not to be satellite driven. This effectively eliminates the Io–controlled portion of the Jovian DAM and, also, the kilometer–wave portions of the Jovian emission since it is still likely that at least some fraction of their emissions is Io driven.

The solar wind input $P_i$ at each planet was computed from

$$P_i = \pi m_p N_o V^3 (L_o/d)^2 \tag{1}$$

which is a measure of the power (W) incident on the cross–sectional area of the magnetosphere due to bulk motion of the solar wind plasma. Here $m_p$ is the proton mass, $N_o$ is the solar wind number density at earth, V is the average solar wind bulk speed, $L_o$ is the solar wind–magnetosphere standoff (Chapman–Ferraro) distance, and d is the planet–sun distance in AU.

Table 1 (from Desch and Kaiser, 1984) summarizes the efficiency comparison at each planet. We have defined the efficiency $\epsilon$ as the ratio of the median power radiated in magnetospheric emissions divided by the incident solar wind power.

| Planet | $P_r$ (W) | Beam (sr) | Spectrum used | $P_i$ (W) | $\epsilon$ $\times 10^{-6}$ |
|---|---|---|---|---|---|
| Jupiter | $4 \times 10^9$ | $\pi/2$ | HOM only | $1.1 \times 10^{15}$ | 3.6 |
| Saturn | $2 \times 10^8$ | $2\pi$ | Full | $3.8 \times 10^{13}$ | 5.3 |
| Earth | $6 \times 10^7$ | 3.5 | Full | $9.6 \times 10^{12}$ | 6.2 |

Table 1: Efficiency comparison

Note that although the emitted radio power varies over two orders of magnitude, the efficiencies are all within a factor of 1.7 of each other. Figure 1 shows the fit to the radiometric Bode's law, using earth, Jupiter and Saturn. The fit is given by

$$(L_o/d)^2 = 6.5 P_r^{1.13} \tag{2}$$

The importance of this equation is that it permits the estimation of a planet's radio emission output $P_r$ based on knowledge of the planet's magnetic moment (and hence stand–off distance) alone.

## 3. Prediction

In order to estimate the magnetic moment of Neptune, we have relied on the recent results of Curtis and Ness (1986) in which a general relationship for interior field strengths is derived on the basis of an expression relating the balance between the Coriolis force within the planet's core and the $\vec{J} \times \vec{B}$ ponderomotive force within the core. The scaling results for the planets and the moon are shown in Figure 2, where the observed and predicted values are compared. Mars, Venus, and the moon are upper limits, and the value derived for Neptune is shown by the filled square. The predicted Neptune value is 0.4 to 0.5 Gauss at the magnetic equator. This puts the standoff distance at about $35R_N$, placing Neptune's major satellite Triton well within the magnetosphere. Given the standoff distance as about $35R_N$ under relaxed solar wind conditions, the radiated power from Neptune may be calculated using (2). The value is 1.5 x $10^7$ W, counting both poles. If only one pole is observable at a time, which is usually the case from a single spacecraft, then the value is half this, and that is what is shown in Figure 1 for Neptune.

We have said nothing about beaming of the radiation since this property of the emission is extremely difficult to anticipate. If the beam is predominantly nightward, which is the case for both the earth and Uranus, then virtually nothing will be known about Neptune's radio emission until the post encounter phase of the mission (cf., Curtis, 1985). If, however, the beam is visible from the inbound trajectory of Voyager, then we should expect first detection of the planet about 45 to 60 days before closest approach. Even in this best–case scenario, there would be far less data to examine than was the case for either Saturn or Jupiter.

## 4. Spectral shape

Given the above prediction concerning Neptune's magnetic moment and the total radiated power, it is possible to put forward a crude estimate of the expected shape of the flux spectrum for Neptune. We show two possibilities in Figure 3, where the median SKR flux spectrum is illustrated for comparison. Two cases, an SKR–like and an AKR–like spectrum, are calculated for Neptune. Each Neptune spectrum is simply the median SKR or AKR spectrum translated up in frequency by an amount proportional to the ratio of the magnetic moment of each planet to Neptune; namely, Neptune:Saturn and Neptune:Earth, respectively. The location of the Neptune spectra along the ordinate is determined by the integral under each curve. The integral corresponds to the total radiated power from a single hemisphere (Table 2), assuming a filled $2\pi$ sr beam.

| PROPERTY | VALUE | NOTES |
|---|---|---|
| Magnetic Moment | 0.4 –0.5 $GR_N^3$ | Curtis and Ness (1986) |
| Standoff Distance | 35–37 $R_N$ | Encompasses Triton |
| Total Radiated Power | $1.5\times10^7 W$ | Counting both hemispheres |
| Low Frequency cutoff | 80 – 150 kHz | See Figure 3 |
| High Frequency cutoff | 1000 – 2000 kHz | See Figure 3 |
| Spectral Peak | 350 – 500 kHz | SKR–like or AKR–like |
| Earliest Detection | 45-60 days before CA | Assumes dayside beaming |

Table 2: Neptune Prediction

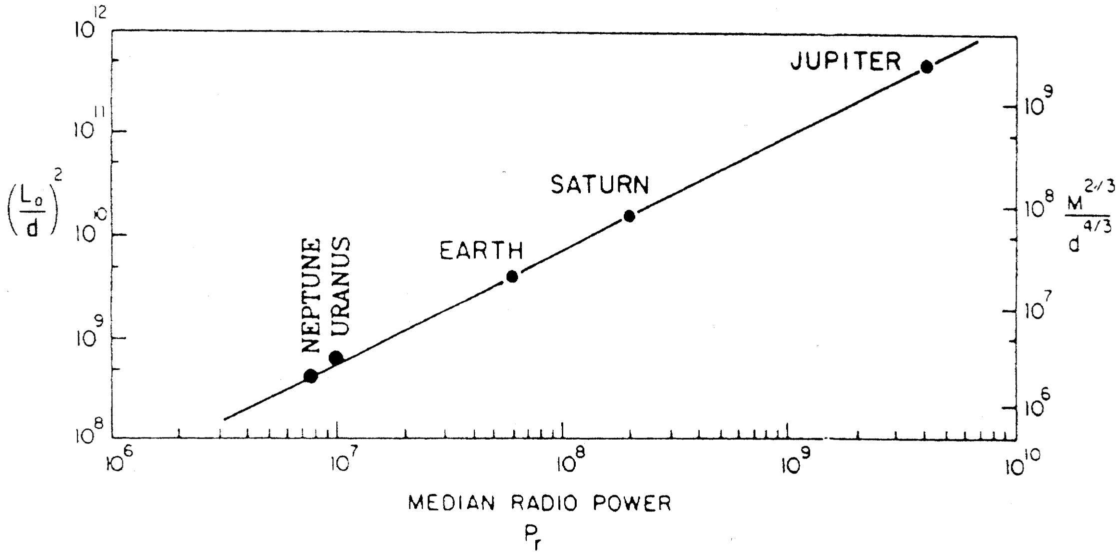


*Fig. 1: The radiometric Bode's Law. The total median radio power is plotted as a function of $(L_o/d)^2$. $L_o$, $d$, and $P_r$ are in units of km, AU and Watts, respectively.*

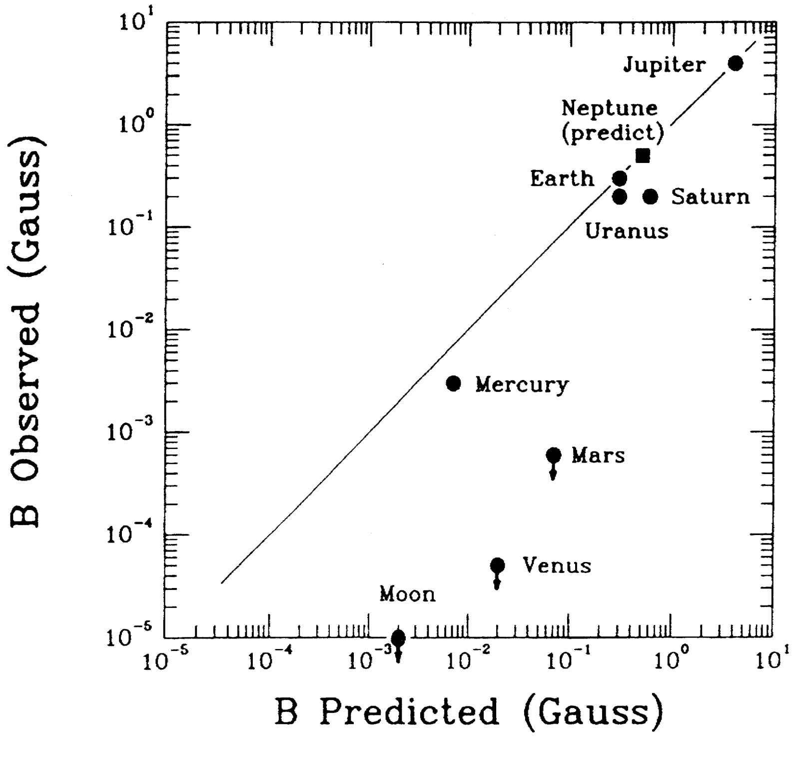


*Fig. 2: Plot of observed magnetic field in gauss versus predicted magnetic field from the magnetospheric balance equation. The predicted value for Neptune appears as a filled square (from Curtis and Ness, 1986).*

The predicted spectra are fairly similar, with the AKR–like spectrum somewhat narrower than the SKR–like. The low–frequency cutoffs are about 80 and 150 kHz for the SKR and AKR–like spectra, respectively, and the high–frequency cutoffs are about 1000 and 2000 kHz. The spectral peaks are at 350 kHz (SKR–like) and 500 kHz (AKR–like).

Obviously a more sophisticated approach to predicting the spectral shape is possible; for example, by actually calculating wave growth rates in the context of the electron maser mechanism (e.g., Wu and Lee, 1979; Le Quéau, 1988, this proceedings) an improved spectrum could be estimated.

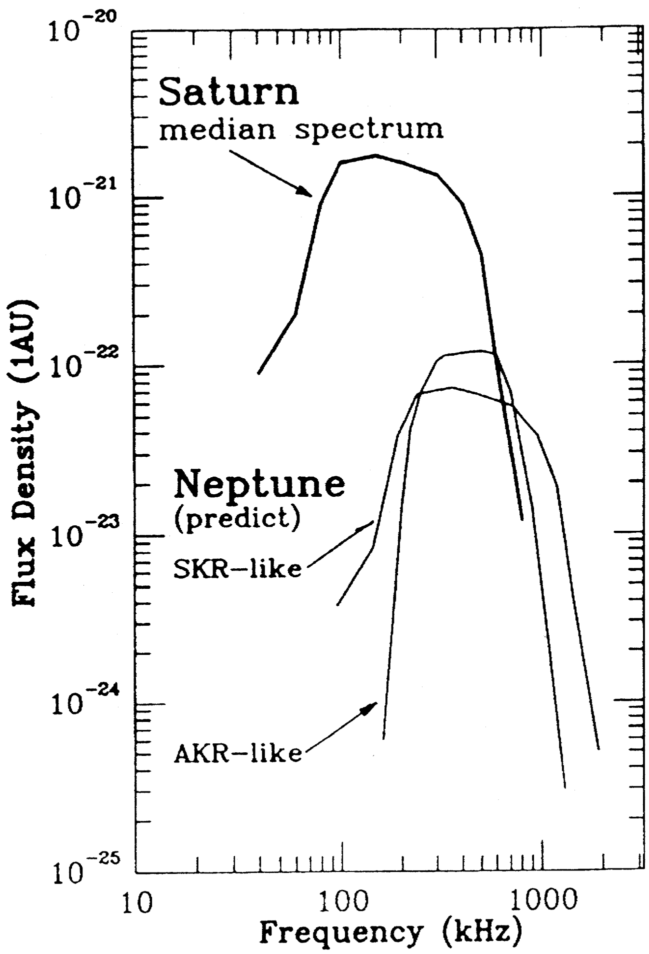


*Fig. 3: Crude estimate of the likely shape of Neptune's median low–frequency radio spectrum. The flux density scale is in absolute units of $W/m^2/Hz$ normalized to a standard distance of 1 AU. The median flux spectrum of the Saturn kilometric radiation (SKR) is shown for comparison. Two shapes for the Neptune spectrum are shown: An AKR case and an SKR case. The restricted frequency range in the AKR case is due to the different plasma–to–gyrofrequency range in the source region.*